Ohio Research Institute
for Transportation
and the Environment

ORITE

Measurement of Dowel Bar Response In Rigid Pavement

ORITE-1 (FHWA)

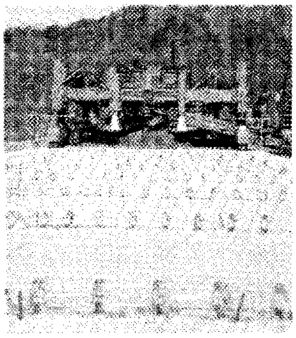


Figure 1—Paving Process

Introduction

The effectiveness of load transfer between adjacent slabs is an important component of long term rigid pavement performance. When load transfer is minimal or non-existent, concrete slabs must carry the full weight of truck axles across their entire length. This condition results in high dynamic tensile stresses being induced in the slab and high dynamic compressive stresses being generated in the base and subgrade. Dowel bars are placed in rigid pavement contraction joints as a mechanism for distributing traffic loads over multiple slabs through vertical shear and/or bending moments, and thereby, reducing stresses in the slab and base. Unfortunately, premature distress is often observed around rigid pavement joints. The purpose of this project was to instrument and install a total of 12 dowel bars in an in-service pavement and monitor their response under environmental cycling and dynamic loading. An examination of this data might provide some insight into the reasons for this premature distress.

Test Site

A suitable site was located approximately five miles east of Athens, Ohio where U.S. 50 was being upgraded from a two-lane facility to a four-lane divided highway. This 254 mm (10 in) thick pavement was to be constructed of high performance concrete, consisting of Southdown-Fairborn Type I cement with Holnam-Grancem ground granulated blast furnace slag, AASHTO #8 gravel coarse aggregate and natural concrete sand. Master Builders Masterpave-N Type A water reducer and Pave Air 90 air entraining admixture were added to complete the mix. The project mix formula was as follows:

Components of PCC mix

Components	**Weight per cubic yard**
Fine Aggregate (dry)	647.7 kg (1428 lbs.)
Coarse Aggregate (dry)	619.1 kg (1365 lbs.)
Cement	186.8 kg (412 lbs.)
Water	143.3 kg (316 lbs.)
GGBFS	62.6 kg (138 lbs.)
Total Weight	1660.6 kg (3661 lbs.)
Water Reducer	56.7 g/cwt (2oz/cwt)
Air Entraining	119.1 g/cwt (4.2 oz/cwt)

The lanes were 3.66 m (12 ft) wide and joint spacing was 6.40 m (21 ft). Load transfer was provided at the joints by baskets of twelve 38 mm (1.5 in) diameter steel dowel bars spaced 305 mm (12 in) on centers. Figure 1 shows concrete being placed at the site.

Sensor Installation

Six dowel bars were instrumented to monitor dynamic and environmental response, as shown in Figure 2. A small area was machined flat on the top and bottom of each bar at its midpoint for Micro-Measurements uniaxial strain gauges and on one side for a 45° rosette. The gauges were either welded to the bars or cemented with AE-10 epoxy. Micro-Measurements M-Coat F components were then used to prevent the intrusion of moisture and protect the gauge and sensor leads. Shallow grooves were cut from the midpoint to the end of the bars to house the lead wires. A small cavity was cut in the end of the bars where the lead wires could be epoxied and protected from the concrete. Three instrumented bars were inserted into each of two dowel bar baskets at positions corresponding to 0.152, 0.762 and 1.981 m (0.5, 2.5, and 6.5 ft) from the outside edge of the pavement. The two baskets were set at consecutive joints.

Thermocouples were installed 0, 76, 152 and 229 mm (0, 3, 6, and 9 in) from the bottom of the slab at four locations near the dowel bars to monitor pavement temperature. The three sensors closest to the bottom of the slab were fabricated into a single unit and attached to the dowel baskets. The top thermocouple was installed during placement of the concrete by making a 25 mm (1 in) deep groove in the green concrete, placing the sensor in the groove, and covering it before finishing was initiated. The concrete pavement was placed on October 14, 1997. Contraction joints were sawed in the pavement directly above the strain gauges to control shrinkage cracking. Figure 3 shows a layout of the strain gauges and thermocouples.

Six additional bars were machined in a similar manner and used in two joints placed on October 13, 1998. Some of these dowel bars were instrumented with fiber optic gauges and installed at identical positions in the pavement to provide redundant strain measurements. Slightly smaller areas were required on the bars for mounting the fiber optic gauges than was required for the wire gauges.

Data Acquisition

The uniaxial and rosette strain gauges were both capable of collecting slow responses due to changes in environmental conditions and fast responses induced by dynamic loads. For environmental responses, data collection was initiated one hour before placement of the concrete and continued at 30-minute intervals for 37 days. Each data point was the average of five readings taken at 60-second increments. The Ohio DOT provided a Dynatest Falling Weight Deflectometer (FWD) for the application of dynamic loads.

The following equation was used to calculate bending moments in the steel dowel bars from average strain measured on the top and bottom of the bars:

$$M_z = \frac{EI(\varepsilon_b - \varepsilon_t)}{2c} \qquad (1)$$

where, M_z = Bending moment.
E = Modulus of elasticity.
I = Moment of inertia.
ε_b, ε_t = Strain at bottom and top.
c = Dowel bar radius.

Figures 4 and 5 are plots of calculated bending moments in the three instrumented bars at Joint 1 of the section poured in 1998 and the difference in the pavement temperature between the top and bottom thermocouples. Figure 4 represents response immediately after the concrete had been placed and Figure 5 is about one month later. These figures show a steady increase in negative moments being introduced into the bars during curing as well as a dramatic correlation between differential temperature in the pavement slab and bending moment in the dowel bars. As the pavement cures or the temperature gradient becomes negative (bottom warmer than the top), the slab ends curl upward and the slab ends rotate from a vertical position. Negative bending moments are generated in the dowel bars as they resist this rotation. While the directions of curvature are consistent with theory, the magnitude of these bending moments and the corresponding stresses in the dowel bars and in the concrete around the bars were much higher than expected. Bearing stresses are of particular concern early in the life of the pavement because the concrete has not attained its full compressive strength.

The magnitude of these bending moments will depend upon the amount of curvature being induced in the slab by curling and warping as well as the extent to which this curvature is being resisted by dowel bar stiffness and the bearing resistance the concrete surrounding the bars. Data from Figures 4 and 5 indicate that all three instrumented bars in Joint 1 were subjected to bending moments of -250 N-m (-184 ft-lb) within 24 hours after placement of the concrete. As the slabs experienced daily temperature cycling, maximum negative moments progressively increased to -300 N-m (-221 ft-lb) after two days, to -350 N-m (-258 ft-lb) after four days and -500 N-m (-368 ft-lb) after a month. Similar data were obtained with the fiber optic gauges. It seems logical that the remaining nine bars in the basket were exposed to similar types of bending moments.

The relationship between bending moment and maximum stress in the dowel bars is related by the familiar expression:

$$\sigma = \frac{Mc}{I} \qquad (2)$$

where, σ = Stress.
M = Bending moment.
c = Dowel bar radius.

For bending moments of -250 and -500 N-m (-184 and -368 ft-lb), tensile stresses in 38-mm (1.5 in) diameter steel dowel bars are 46.1 and 92.2 MPa (6.6 and 13.2 ksi)

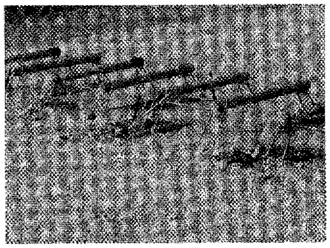
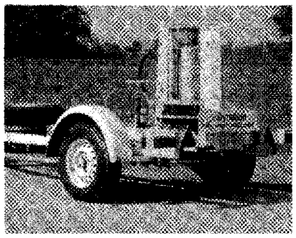


Figure 6—Instrumented Dowel Bars



Falling Weight Deflectometer

respectively. While these stresses are well within the working limit of 138 MPa (20.0 ksi), they are quite significant in magnitude.

The calculation of concrete bearing stress around the dowel bars involves certain assumptions, as shown in the following equation:

$$\sigma_B = K\left[\frac{P - \beta M}{2\beta^3 EI}\right] \qquad (3)$$

where, σ_B = Bearing stress.
K = Stiffness.
P = Shear Force on a dowel bar.
$\beta = \sqrt[4]{\frac{Kd}{4EI}}$
d = Dowel bar diameter.

Using parameters typical for Ohio, bending moments of –250 to –500 N-m (-184 to –368 ft-lb) in 38 mm (1.5 in) diameter steel dowel bars translates to bearing stresses of 4.6 and 9.3 MPa (671 and 1343 psi) respectively in the Portland cement concrete (PCC). The allowable bearing stress of fully cured concrete is 23 MPa (3300 psi), as calculated with the empirical equation:

$$f_b = \frac{(4 - d)}{3} f'_c \qquad (4)$$

where,
f_b = Allowable bearing stress (psi).
d = Dowel bar diameter (in).
f'_c = Ultimate compressive strength of concrete (psi).

During curing, the allowable bearing stress of PCC increases as its ultimate compressive strength increases. Therefore, the rate at which concrete attains its bearing strength must exceed the rate at which bearing stress is developed around the dowel bars. If applied bearing stress is greater than the concrete is able to withstand, some type of distress will ensue. Increasing the number or diameter of the bars to reduce concrete bearing stress may not be effective since the overall rigidity of the joint and the induced moment will also be increased. In situations where temperature gradients will exceed those measured on U.S. 50 during these tests, bending stresses in the dowel bars and bearing stresses in concrete will be even higher.

FWD loads were applied as the load plate was sitting on both sides of the joint (approach and leave) and centered on the joint. The average magnitude of the load was 57 kN (12800 lb). Bending moments at the wheel path dowel averaged +20 N-m (+15 ft-lb) with the load plate on the approach side of the joint, +45 N-m (+33 ft-lb) with the plate centered on the joint, and +40 N-m (+30 ft-lb) with the plate on the leave side of the joint. The highest single measured bending moment was +69 N-m (+51 ft-lb) on the leave side. Because moments recorded on the approach and leave sides of the joint were not equal, it is likely the shrinkage crack propagating downward from the sawed contraction joint did not go straight through the gauges on the dowel bars. Bending moments induced by the FWD loads on steel dowel bars were less than bending moments observed above during curing and daily temperature cycling. Because of the FWD positioning, positive moments were applied to the dowel bars, which negated a portion of the larger negative environmental moments. Dynamic loading at other slab locations would likely have resulted in additional negative moments. This data strongly suggest the need to include environmental parameters in dowel bar design procedures.

Conclusions

At the present time, dowel bars are installed in PCC pavement contraction joints to transfer traffic loads to adjacent slabs. When used correctly, dowel bars significantly improve the performance of rigid pavements. However, premature distress is still observed at PCC joints and there is concern regarding the magnitude of forces being carried by these bars. In this study, the magnitude of bending moments generated in the instrumented steel dowel bars as they resist slab curvature during curing and temperature cycling exceeded those generated by FWD loading over the

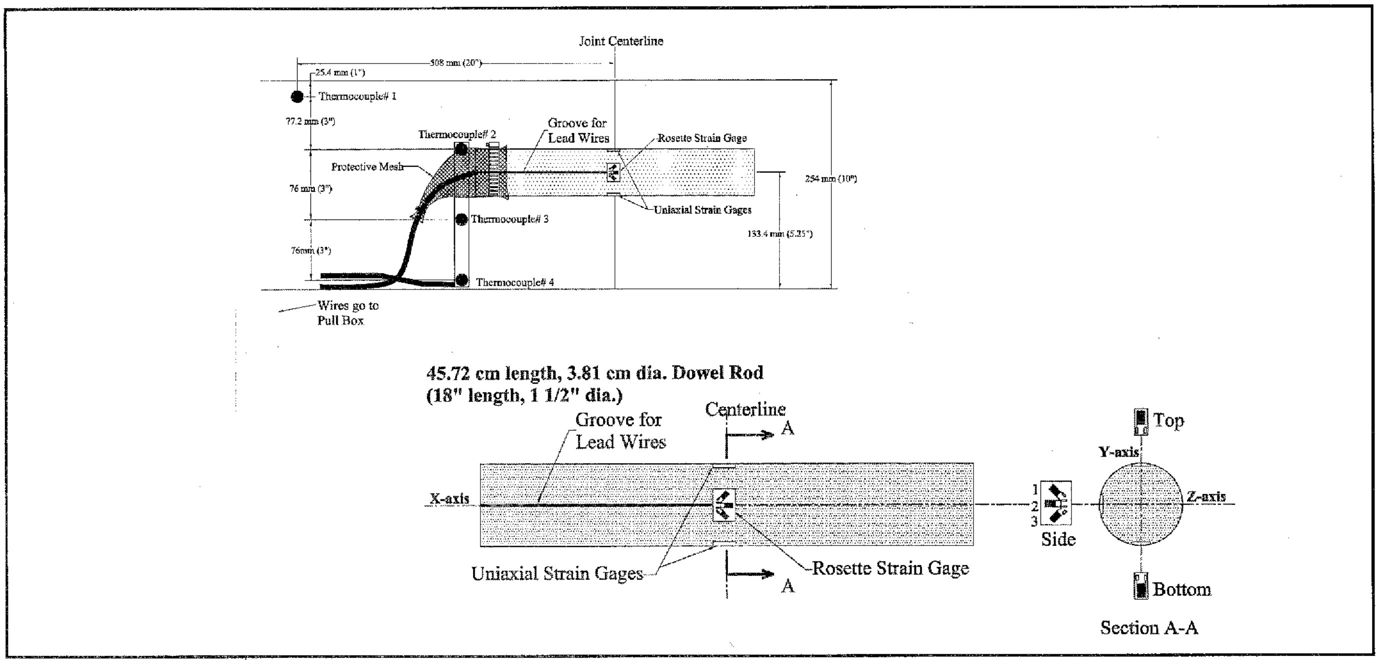


Figure 2—Side View of Thermocouple and Strain Gauge Installation Plan for Dowel Bars

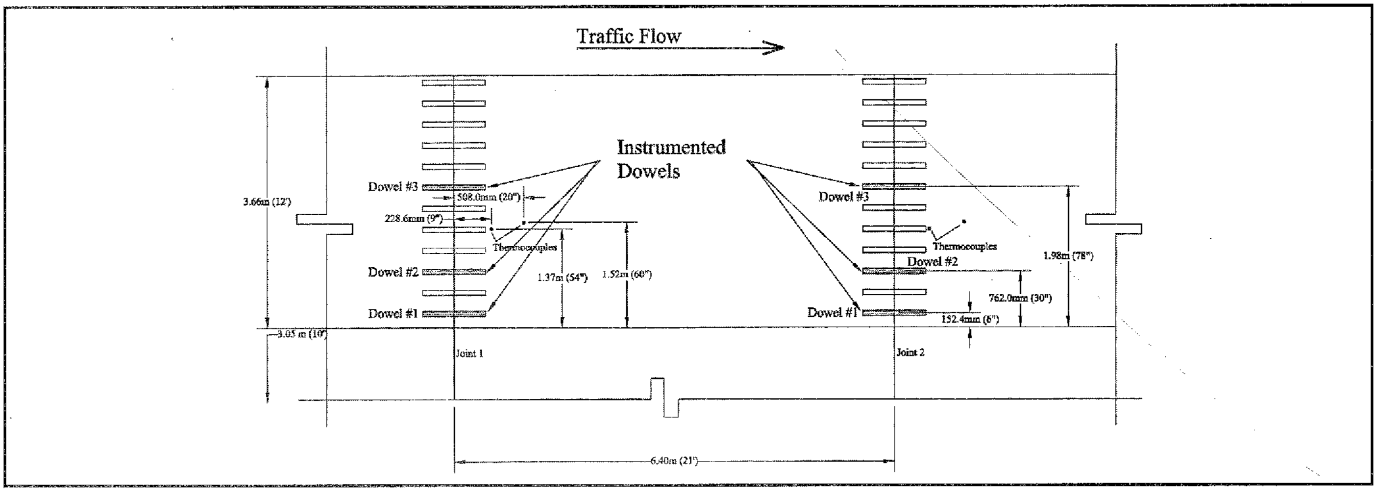


Figure 3—Typical Section Instrumentation Plan

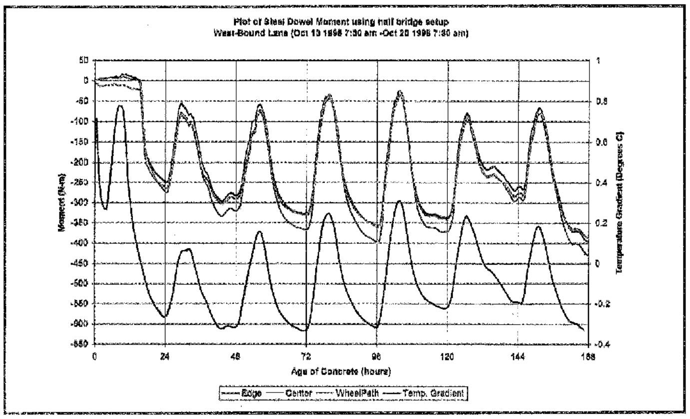


Figure 4—Typical Steel Dowel Environmental Moment Data

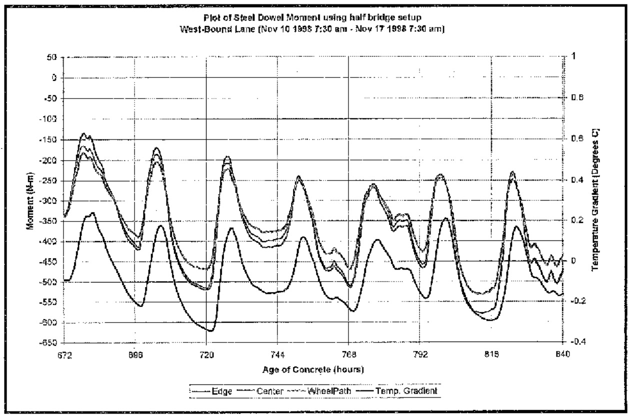
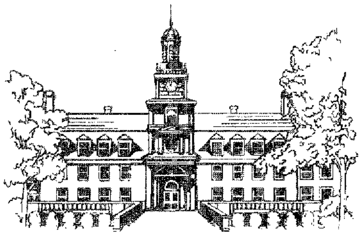


Figure 5—Typical Steel Dowel Environmental Data

joints. These environmental moments will be even greater in situations where larger temperature gradients are present. As repeated applications of high bearing stress are incurred throughout the life of the pavement, concrete at the dowel bar interface will wear away, gradually resulting in looseness around the bars. This loss of material will provide some relaxation in the dowel bar bending stresses and concrete bearing stresses, but also will reduce the effectiveness with which dowel bars transfer load and limit environmental slab deformations.

From data obtained in this study, it appears the design of dowel bars for rigid pavement joints involves a delicate balance between resisting slab curvature induced by concrete curing and temperature gradients, transferring dynamic load to adjacent slabs, and maintaining an acceptable bearing stress in concrete around the dowel bars. As load transfer systems become more rigid, slab curvatures are reduced and dynamic loads are distributed better across the slabs, but this rigidity results in greater bending moments being transferred to the concrete. If load transfer systems are made less rigid, slabs will experience greater environmental curvature and more nonuniform support for carrying traffic loads, leading to higher tensile stress in the slab and higher compressive stress in the supporting layers.

The scope of this study was limited to one dowel bar configuration in one pavement and the application of FWD loads adjacent to or straddling the joints. For this dynamic loading condition, the resulting bending moments on the dowel bars were positive, thereby reducing the large negative environmental moments. It is likely FWD loading at other locations on the slab or actual moving truck loads will generate negative moments that, when superimposed on the environmental moments, will increase the concrete bearing stress even more. Considering the complexity of issues raised in this research, additional investigations are needed to clearly identify the manner in which dowel bars can be designed most effectively to carry traffic loads without exceeding the strength limitations of the materials involved.



For Further Information:

Dr. Shad Sargand
Ohio University
Ohio Research Institute
for Transportation and
the Environment
Stocker Center
Athens, Ohio 45701
740-593-2476
Fax: 740-593-0625
orite@bobcat.ent.ohiou.edu
http://webce.ent.ohiou.edu/orite

Funding for this research provided by FHWA under "Testing and Evaluation of High Performance Concrete for Pavement" (TE-30)